TITLE OF THE INVENTION

PROTECTION RELAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2001-057948, filed March 2, 2001, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a protection relay in which an influence of distortion component of fault current generated by a fault in a power system is suppressed.

2. Description of the Related Art

Generally, a protection relay is used to monitor a power system. A main technical subject of such a protection relay is to reduce an influence of harmonics in fault current and fault voltage generated in a fault in a system contained in a signal inputted from the system.

Particularly because charging capacity of a system is increased in underground power transmission cable, phase modifying capacitor and the like, the order of generated harmonics tends to be lowered.

Thus, if it is intended to secure a desired damping amount according to a conventional method for

damping the harmonic component with a digital filter, filter delay time needs to be prolonged, so that relay operation time is delayed.

For the reason, an approximation method, which is not affected by harmonic theoretically even if such harmonics is contained has been employed in recent years.

An example of such approximation method will be described with reference to FIG. 1. Power transmission impedance constant up to a fault point F will be considered with reference to FIG. 1. Voltage and current of a protection relay installation point A are assumed to be v and i when resistance is R and inductance is L. If it is assumed that the voltage at the faultal point F is zero, differential equation of a power transmission line 2 can be expressed in an expression (1).

$$V = R \cdot I + L \cdot (di/dt) \qquad \cdots (1)$$

By calculating a differential item (di/dt) of the expression (1) approximately, detection accuracy can be improved even if harmonic is not removed with a filter. An example of a concrete method for digital calculation actually adapted is shown below.

$$v_m + v_{m-1} = R \cdot (i_m + i_{m-1}) + L \cdot (i_m - i_{m-1})$$

$$v_{m-1} + v_{m-2} = R \cdot (i_{m-1} + i_{m-2}) + L \cdot (i_{m-1} - i_{m-2}) \qquad \cdots (2)$$

When a reactance value X (= $\omega_0 \cdot L$) is calculated from the expression (2), the inductance is expressed in

expression (3).

$$L_m = X_m / \omega_0 =$$
$$\frac{(v_m + v_{m-1}) \cdot (i_{m-1} + i_{m-2}) - (v_{m-1} + v_{m-2}) \cdot (i_m + i_{m-1})}{(i_m - i_{m-1}) \cdot (i_{m-1} + i_{m-2}) - (i_{m-1} - i_{m-2}) \cdot (i_m + i_{m-1})}$$
$$\cdots (3)$$

L_m/L (true value) is as expressed in the expression (4) under conditions of the expressions (5) and (6), so that frequency characteristic of X_m/X (true value) is as indicated with the dotted curve of FIG. 2.

$$L_m/L(\text{true value}) = \tan(\omega_0 T/2)/\tan(\omega T/2) \quad \cdots (4)$$

Where, $i_m = I\sin(\omega t_m)$, $v_m = V\sin(\omega t + \theta)$

$$i_m - i_{m-1} = 2I\sin(\omega T/2)\cos(\omega t_m - \omega T/2) \quad \cdots (5)$$

$$v_m + v_{m-1} = 2V\cos(\omega T/2)\sin(\omega t_m - \omega T/2 + \theta) \quad \cdots (6)$$

Therefore, frequency characteristic of X_m/X (true value) is as indicated with the dotted curve of FIG. 2.

In FIG. 2, its abscissa axis indicates frequency (order) and its ordinate axis indicates a reactance measurement value when basic frequency of system electrical quantity is 50 Hz. Further, in FIG. 2, its dotted curve indicates a case of sampling at 600 Hz and its solid line indicates a case of sampling at 4800 Hz.

As indicated in FIG. 2, the value of L_m/L (true value) decreases below 1 as the frequency departs from its fundamental wave. FIG. 2 indicates that the value of $(\omega T/2)$ only should be suppressed to substantially 1 (that is, the sampling period should be set small) when this value (L_m/L) is near twice or three times the

fundamental wave.

Frequency characteristic when the sampling frequency is actually multiplied eight times is indicated by the solid line of FIG. 2. Qauntitavely, the relation between an approximate amount $(i_m - i_{m-1})$ of the differential item and a differentiated amount $(v_m + v_{m-1})$ is indicated by the expressions (7) and (8). Therefore, if the sampling frequency is raised (the period is decreased), approximation accuracy of the differential item can be raised.

$$\sin(\omega T/2) = \omega T/2, \cos(\omega T/2) = 1$$

$$i_m - i_{m-1} = 2I \cdot \sin(\omega T/2) \cdot \cos(\omega t_m - \omega T/2)$$

$$= 2I \cdot \omega T/2 \cdot \cos(\omega t_m - \omega T/2) \qquad \cdots (7)$$

$$v_m + v_{m-1} = 2V \cdot \cos(\omega T/2) \cdot \sin(\omega t_m - \omega T/2 + \theta)$$

$$= 2V \cdot \sin(\omega t_m - \omega T/2 + \theta) \qquad \cdots (8)$$

However, the value of the expression (7) is a very small value with respect to an amplitude value I. Therefore, a relative value of noise (quantization error generated at the time of A/D conversion, white noise generated in an analog circuit) contained in sampling data (i_m, i_{m-1}) is increased thereby disabling practical use of this method.

For example, when the sampling period T is $T = 1/4800$ sec, $\omega_0 = 2\pi \cdot 50$ Hz, the second item $\varepsilon/(\omega 0T/2)$ on the right side of the expression (9) is amplified to about 30 times. An ε in the expression (9) is noise error.

$$(i_m - i_{m-1}) / (\omega_0 T/2)$$

$$= 2I \cdot (\omega / \omega_0) \cdot \cos(\omega t_m - \omega T/2) + \varepsilon / (\omega_0 T/2) \quad \cdots (9)$$

BRIEF SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an improved protection relay.

A protection relay for determining whether or not a faultal point of a power system exists in a predetermined range, according to a first aspect of the present invention is characterized by comprising: filter means for inputting sampling data of a voltage and a current in the power system to a digital filter having a predetermined transfer function and outputting a first voltage data and a first current data, and a second voltage data and a second current data normal to the first voltage data and the first current data, respectively; calculation means for calculating a predetermined measurement value based on the first voltage data, the first current data, the second voltage data and the second current data at a first time and the first voltage data, the first current data, the second voltage data and the second current data at a second time different from the first time; and operation decision means for performing an operation decision based on the predetermined measurement value obtained by the calculation means.

A protection relay for determining whether or not a faultal point of a power system exists in

a predetermined range, according to a second aspect of

the present invention is characterized by comprising:

filter means in which sampling data of voltage and

current in the power system is inputted to a predete-

5   rmined transfer function so as to output first voltage

data and first current data and second voltage data and

second current data normal to the first voltage data

and the first current data, respectively; polarized

voltage value calculation means for inputting the first

10   and second voltage data and the first and second

current data so as to calculate a third voltage normal

to the first voltage; and operation decision means for

performing an operation decision based on the third

voltage.

15   A protection relay for determining whether or not

a faultal point of power system exists in a predeter-

mined range, according to a third aspect of the present

invention is characterized by comprising: first filter

means for inputting sampling data v_m and i_m of voltage

20   v and current i in the power system to a digital

filter having transfer function $f(Z) \cdot (1+k \cdot Z^{-1}+Z^{-2})$

(Z indicates a Z conversion operator) so as to output

voltage data v_{sm} and current data i_{sm}; second filter

means in which the sampling data v_m, i_m are inputted to

25   a digital filter having transfer function $f(Z) \cdot (1-Z^{-2})$

(Z indicates a Z conversion operator)so as to output

voltage data v_{jm} and current data i_{jm} normal to the

voltage data v_{sm} and current data i_{sm}; charging current

compensation calculation means for calculating quantity

of electricity defined in $i_{sm}-C \cdot v_{jm}$ by the current

data i_{sm}, the voltage data v_{jm}, and a setting value

5   C_S at time t_m; transmission and reception means

for transmitting output of the charging current

compensation calculation means to an opposite terminal

and when quantity of electricity at the opposite

terminal is assumed to be B, receiving quantity of

10   electricity defined by $(i_{sm}-C \cdot v_{jm})B$ at the opposite

terminal; and operation decision means for performing

an operation decision based on outputs from the

charging current compensation calculation means and

the transmission/reception means according to the

15   following expression:

$$\| (i_{sm}-Cs \cdot v_{jm}) + (i_{sm}-Cs \cdot v_{jm})B \| \geqq$$

$$ka \cdot \{ \| i_{sm}-Cs \cdot v_{jm} \| + \| (i_{sm}-Cs \cdot v_{jm})B \| \}+kb$$

where, $\|am\|$ represents a quantity parallel to amplitude

of AC quantity of electricity "a" at time t_m;

20   ka represents a proportion restricting

coefficient; and

          kb represents minimum sensitivity current.

          Additional objects and advantages of the invention

will be set forth in the description which follows, and

25   in part will be obvious from the description, or may

be learned by practice of the invention. The objects

and advantages of the invention may be realized and

obtained by means of the instrumentalities and

combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated

5 in and constitute a part of the specification,

illustrate embodiments of the invention, and together

with the general description given above and the

detailed description of the embodiments given below,

serve to explain the principles of the invention.

10 FIG. 1 is a power system diagram, which is

an object of the present invention;

FIG. 2 is a diagram showing frequency

characteristic of a reactance measurement value which

is an object of the present invention;

15 FIG. 3 is a diagram showing frequency character-

istic of a reactance measurement value in a digital

filter structure, which is an object of the present

invention;

FIG. 4 is a block diagram of a protection relay

20 according to a first embodiment of the present

invention;

FIG. 5 is a block diagram of a protection relay

according to a first modification of the first

embodiment;

25 FIG. 6 is a diagram showing reactance

characteristic on an impedance plane;

FIG. 7 is a block diagram of a protection relay

according to a second modification of the first

embodiment;

FIG. 8 is a block diagram of a protection relay

according to a third modification of the first

5 embodiment;

FIG. 9 is a diagram showing Ohm characteristic on

an impedance plane:

FIG. 10 is a block diagram of a protection relay

according to a second embodiment of the present

10 invention;

FIG. 11 is a diagram showing offset mho

characteristic on an impedance plane;

FIG. 12 is a block diagram of a protection relay

according to a third embodiment of the present

15 invention;

FIG. 13 is a diagram showing the relation between

maximum sensitive angle of mho characteristic and

permanent impedance;

FIG. 14 is a diagram showing mho characteristic

20 expressed with reference to current;

FIG. 15 is a block diagram of a protection relay

according to a first modification of the third

embodiment;

FIG. 16 is a block diagram of a protection relay

25 according to a second modification of the third

embodiment;

FIG. 17 is a block diagram of a protection relay

according to a fourth embodiment of the present invention; and

FIG. 18 is a diagram for explaining a telegraph equation of a power transmission line.

DETAILED DESCRIPTION OF THE INVENTION

Prior to description of respective embodiments of the present invention, the principle of the present invention will be described. If sampling data of current $i = I \cdot \sin(\omega t)$ is passed through transfer function $f(Z) = (1 + Z^{-1} + Z^{-2} + \cdots + Z^{-n})$, current i'_{sm} at time t_m indicated in the expression (10) is obtained.

$$I'_{sm} = I \cdot (\sin(\omega t_m) + \sin(\omega t_m - \omega T) + \cdots + \sin(\omega t_m - n\omega T))$$
$$= I \cdot (\sin((n+1)\omega T/2)/\sin(\omega T/2)) \cdot \sin(\omega t_m - n\omega T/2)$$
$$\cdots (10)$$

If this current i'_{sm} is passed through transfer function $(1 + k \cdot Z^{-1} + Z^{-2})$, current i_{sm} at time t_m indicated in the expression (11) is obtained.

$$i_{sm} = i'_{sm} + k \cdot i'_{sm-1} + i'_{sm-2}$$
$$= I \cdot (k + 2\cos(\omega T)) \cdot (\sin((n+1)\omega T/2)/$$
$$\sin(\omega T/2)) \cdot \sin(\omega t_m - (n+2)\omega T/2) \quad \cdots (11)$$

Likewise, current $i = I \cdot \sin(\omega t)$ is passed through the transfer function $f(Z) \cdot (1 - Z^{-2})$, current i_{jm} at time t_m is obtained as indicated in the expression (12).

$$i_{jm} = 2I \cdot \cos(\omega T/2)\sin((n+1)\omega T/2) \cdot \cos(\omega t_m - (n+2)\omega T/2)$$
$$\cdots (12)$$

Voltage can be obtained in the same manner as current and if it is assumed that the voltages are v_{sm}

and v_{jm}, they are in such a relation that they are normal to each other.

Thus, if as the fundamental wave, its value which is as near 1 as possible is selected as long as the quantity for determining the size of the right side of the expression (12) is not $|\sin((n+1)\omega T/2)| \ll 1$, performance of frequency characteristic can be assured while suppressing amplification of noise error.

Therefore, if i_{jm}, i_{sm}, and v_{sm} at time t_m and i_{jm-1}, i_{sm-1}, and v_{sm-1} at time t_{m-1} are substituted for:

$$X_m = \frac{-v_{sm} \cdot i_{sm-p} + i_{sm} \cdot v_{sm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}} \quad \cdots (13)$$

where m and p represent sampling time series, voltage v_{sm} is provided in the form of:

$$v_{sm} = V \cdot (k + 2\cos(\omega T)) \cdot (\sin((n+1)\omega T/2) /$$
$$\sin(\omega T/2) \cdot \sin(\omega t_m + \theta - (n+2)\omega T/2) \quad \cdots (14)$$

As a result, a reactance value X_m is indicated in the expression (15):

$$X_m = \frac{V(k + 2\cos(\omega T))}{I \sin(\omega T)} \cdot \sin(\theta) \quad \cdots (15)$$

where θ represents a leading angle of Voltage to current.

Therefore, when n is increased sufficiently in the expression (12), an influence of the noise error can be reduced. Frequency characteristic of X_m relative to the fundamental wave can be indicated in

a graph shown in FIG. 3. From this graph, it is
evident that k = 4 provides the most excellent
frequency characteristic.

Xm/X (value at fundamental wave)

$$= \frac{(k + 2\cos(\omega T))/(k + 2\cos(\omega_0 T))}{\sin(\omega T)/\sin(\omega_0 T)} \qquad \cdots(16)$$

A protection relay according to a first embodiment
of the present invention will be described based on
the above-described principle with reference to FIG. 4.
FIG. 4 is a block diagram showing schematically the
structure of the protection relay according to the
first embodiment. The protection relay of the first
embodiment suppresses amplification of the noise error
contained in minute quantity of data even when the
sampling period is shortened, in order to secure
performance of frequency characteristic indicated
in the expression (4).

Referring to FIG. 4, a first (digital) filter 1
comprises a digital filter (Z indicates a Z conversion
operator) which outputs sampling data v_m and i_m about
voltage v and current i of a power system as voltage
data v_{sm} and current data i_{sm} through transfer function
$f(Z) \cdot (1+k \cdot Z^{-1}+Z^{-2})$ and extracts predetermined frequency
components of voltage and current of a power system
(not shown), which is a protecting object.

A second (digital) filter 2 comprises a digital
filter (Z indicates a Z conversion operator) which

outputs sampling data v_m and i_m as voltage data v_{jm} and i_{jm} through transfer function $f(Z) \cdot (1-Z^{-2})$ and extracts voltage and current normal to the first filter 1 in all frequency components.

5   A reactance value calculator 3 calculates a reactance value X_m from voltage data v_{sm}, current data i_{sm}, voltage data v_{jm} and voltage data i_{jm} at time t_m and voltage data i_{sm-p}, current data i_{sm-p}, voltage data v_{jm-p} and current data i_{jm-p} at time t_{m-p}.

10   An operation decision section 4 compares the reactance value X_m obtained by the reactance calculator 3 with a preliminarily set integer (whether or not $X_m \leq X_S$ is determined with X_S). The preliminarily set integer value is called setting value in this

15 specification.

     With such a configuration, the first filter having the transfer function $f(Z) \cdot (1+k \cdot Z^{-1}+Z^{-2})$ receives input of sampling data v_m and i_m about voltage v and current i of the power system and outputs voltage data v_{sm} and

20 current data i_{sm}.

     Further, the second filter having the transfer function $f(Z) \cdot (1-Z^{-2})$ receives input of sampling data v_m and i_m about the voltage v and current i and outputs voltage data v_{jm} and current data i_{jm}.

25   The reactance value calculator 3 calculates a reactance value X_m from the voltage data v_{sm} and current data i_{sm} obtained by the first filter 1 and

voltage data v_{jm} and current data i_{jm} obtained by the

second filter 2 at time t_m, and voltage data v_{sm-p} and

current data i_{sm-p} obtained by the first filter 1 and

voltage data v_{jm-p} and current data i_{jm-p} obtained by

5   the second filter 2 at time t_{m-p} according to the

expression (17):

$$X_m = \frac{-v_{sm} \cdot i_{sm-p} + i_{sm} \cdot v_{sm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}} \qquad \cdots (17)$$

where, m and p represent sampling time

10   series.

Further, the operation decision section 4 decides

whether or not $X_m \leq X_s$ is established from the

reactance value X_m and setting value X_s obtained by the

reactance value calculator 3 and when that relation is

15   established, it decides it is active and otherwise,

it decides it is inactive.

The transfer functions of the first and second

filters 1 and 2 are expressed in $f(Z) \cdot (1+k \cdot Z^{-1}+Z^{-2})$

and $f(Z) \cdot (1-Z^{-2})$ when the Z conversion operator is

20   employed. As already described before, the outputs of

the first and second filters 1 and 2 are normal to each

other. There is a relation that the output of the

first filter 1 is delayed at 90° with respect to the

output of the second filter 2.

25   It is permissible to define these transfer

functions with transfer function 1: $f(Z)$,

transfer function 2: $(1+k \cdot Z^{-1}+Z^{-2})$ and transfer

function 3: $1-Z^{-2}$ and form the first filter 1 and
the second filter 2 by combining those.

That is, the same output can be obtained by
passing the input voltage and current through a digital
5   filter of the transfer function 1 and then passing its
output through digital filters of the transfer
functions 2 and 3.

The reactance value calculator 3 of FIG. 4
calculates a reactance value from a protection relay
10   installation point in a power transmission line of
FIG. 1 up to a faultal point according to the
expression (17). Assuming that the input voltage
and current are $i = I \cdot \sin(\omega t)$, and $v = V \cdot \sin(\omega t + \theta)$,
the expression (17) can be expressed in the
15   expression (15).

The operation decision section 4 corrects the
decision expression using the reactance value X_m,
setting value X_s and preliminarily set fundamental wave
constant $\sin(\omega_0 T)/(k+2 \cdot \cos(\omega_0 T))$ with respect to the
20   reactance value X_m calculated by the reactance value
calculator 3 as indicated in the expression (18) so as
to decide whether or not it is active. Such operation
decision is carried out plural times ordinarily.

$$X_m \leq X_s/(\sin(\omega_0 \cdot T)/(k+2 \cdot \cos(\omega_0 \cdot T)) \qquad \cdots (18)$$

25   Consequently, amplification of error due to
approximation of the differential item is suppressed,
so that L_m/L (true value) becomes a characteristic

which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

According to the above description, the reactance value calculator 3 calculates the reactance value using outputs of the first filter 1 and the second filter 2 and the operation decision section 4 decides whether or not it is active according to the condition expression (18) based on that reactance value.

The present invention is not restricted to this example, but it is permissible for an operating restarint quantity calculator 5 to calculate a_m and b_m according to the expression (19) based on the outputs of the first filter 1 and the second filter 2 and then for an operation decision section 6 to decide the operation according to the expression (20) to be described later using that result.

$$a_m = -v_{sm} \cdot i_{sm-p} + v_{sm-p} \cdot i_{sm}$$
$$b_m = -i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm} \qquad \cdots (19)$$

That is, when current $i = I \cdot \sin(\omega t)$ and voltage $v = V \cdot \sin(\omega t + \theta)$ are inputted to the first filter 1 of the transfer function $f(Z) \cdot (1 - k \cdot Z^{-1} + Z^{-2})$ and the second filter 2 of the transfer function $f(Z) \cdot (1 - Z^{-2})$, the expression (19) is converted to the expression (20), providing that $f(Z) = (1 + Z^{-1} + Z^{-2} + \cdots + Z^{-n})$.

$$a_m = IV\{(k+2\cos(\omega T))^2 \cdot$$

$$(\sin((n+1)\omega T/2)/\sin(\omega T/2))^2\} \cdot \sin(\theta) \cdot \sin(p\omega T)$$

$$b_m = 2I^2\{\cos(\omega T/2) \cdot \sin((n+1)\omega T/2) \cdot$$

$$(k+2\cos(\omega T)) \cdot (\sin((n+1)\omega T/2)/\sin(\omega T/2))\}$$

$$\cdot \sin(p\omega T) \qquad\qquad \cdots(20)$$

The operation decision section 6 corrects sensitivity constant K_0 and reactance setting value X_s to $X_s \leftarrow X_s/(\sin(\omega_0 T)/(k+2\cdot\cos(\omega_0 T))$ using a_m and b_m outputted in this way and decides the operation according to a decision expression of the expression (21).

$$b_m \cdot X_m - a_m \geq k_0 \qquad\qquad \cdots(21)$$

Although this is a different method from the above-described method, it has the reactance characteristic as shown in FIG. 6 like that example.

Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

Further, it is permissible to use an Ohm value calculator 7 defined by expression (22) as shown in FIG. 7 as such calculation means or an operation decision section 8 defined by the expression (25),

which will be described later.

$$R_m = \frac{-i_{jm} \cdot v_{sm-p} + v_{sm} \cdot i_{jm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}} \qquad \cdots (22)$$

With this configuration, when current

i = I·sin(ωt) and voltage v = V·sin(ωt+θ) are inputted

into the first filter 1 of the transfer function

$f(Z) \cdot (1+k \cdot Z^{-1}+Z^{-2})$ and the second filter 2 of the

transfer function $f(Z).(1-Z^{-2})$, the expression (23)

is established, providing that $f(Z) = (1+Z^{-1}+Z^{-2}+ \cdots$

$+Z^{-n})$. Further, the Ohm value R_m is converted to the

expression (24) because of the relation of the

expression (20).

$$-i_{im} \cdot v_{sm-p} + i_{jm-p} \cdot v_{sm}$$
$$= 2IV\cos(\omega T/2) \cdot \sin((n+1)\omega T/2) \cdot (k+2\cos(\omega T)) \cdot$$
$$(\sin((n+1)\omega T/2)/\sin(\omega T/2)) \cdot \cos(\theta) \cdot \sin(p\omega T)$$
$$\cdots (23)$$

$$R_m = (V/I) \cdot \cos(\theta) \qquad \cdots (24)$$

The operation decision section 8 decides whether

or not a decision expression for the expression (25) is

established based on the Ohm value R_m and the setting

value R_S calculated from the expression (24) and when

that expression is established, it decides it is

active.

$$R_m \leq R_S \qquad \cdots (25)$$

Consequently, amplification of error due to

approximation of the differential item is suppressed,

so that L_m/L (true value) becomes a characteristic

which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

Further, it is permissible to use an operation restricting quantity calculator 9 defined by the expression (26) shown in FIG. 8 or an operation decision section 10 defined by the expression (28) which will be described later, as such calculation means.

$$c_m = -i_{jm} \cdot v_{sm-p} + v_{sm} \cdot i_{jm-p}$$
$$b_m = -i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm} \qquad \cdots (26)$$

That is, when current $i = I \cdot \sin(\omega t)$ and voltage $v = V \cdot \sin(\omega t + \theta)$ are inputted to the first filter 1 of the transfer function $f(Z) \cdot (1 - k \cdot Z^{-1} + Z^{-2})$ and the second filter 2 of the transfer function $f(Z) \cdot (1 - Z^{-2})$, the expression (26) is converted to the expression (27), providing that $f(Z) = (1 + Z^{-1} + Z^{-2} + \cdots + Z^{-n})$.

$$
\begin{aligned}
m &= -i_{jm} \cdot v_{sm-p} + i_{jm-p} \cdot v_{sm} \\
&= 2IV\cos(\omega T/2) \cdot \sin((n+1)\omega T/2) \cdot (k + 2\cos(\omega T)) \cdot \\
&\quad (\sin((n+1)\omega T/2)/\sin(\omega T/2)) \cdot \cos(\theta) \cdot \sin(p\omega T)
\end{aligned}
$$
$$\cdots (27)$$

Then, the operation decision section 10 decides whether or not it is active based on the decision expression (28) from c_m, b_m, Ohm setting value R_s and sensitivity constant K_1.

$$R_s - c_m \geq k_1 \qquad\qquad \cdots (28)$$

Such protection relay has Ohm characteristic shown in FIG. 9 like the configuration described with reference to FIG. 7 before and is different from it only in its realization method.

Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

Next, a second embodiment of the present invention will be described with reference to the accompanying drawings. A description of the same configuration as the above-described embodiment is omitted appropriately while like reference numerals are attached to the same components in the Figures.

According to the first embodiment, for example, FIG. 4 indicates calculation of reactance and FIGS. 5, 8 indicate calculation of operating restarint quantity, and FIG. 7 indicates calculation of Ohm value and decision of operation based thereon.

This embodiment contains the Ohm value calculator 7 and reactance value calculator 3 as shown in FIG. 10 and then, the operation decision section 11 decides

the operation using these outputs.

That is, the voltage v_{sm}, current i_{sm} and voltage v_{jm}, current i_{jm} outputted from the first filter 1 and the second filter 2 are inputted to the Ohm value calculator 7 for calculating Ohm value and the reactance value calculator 3 for calculating reactance. The Ohm value calculator 7 calculates an Ohm value R_m according to the expression:

$$R_m = \frac{-\,i_{jm} \cdot v_{sm-p} + v_{sm} \cdot i_{jm-p}}{-\,i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}}$$

The reactance value calculator 3 calculates reactance X_m according to the expression (13).

The operation decision section 11 decides whether or not it is active according to the expression (29) using the Ohm value R_m and the reactance value X_m. This protection relay has offset mho characteristic indicated in FIG. 11:

$$(R_m - R_0) \cdot (R_m - R_p) + (X_m - X_0) \cdot (X_m - X_F) \leq 0 \qquad \cdots (29)$$

where, R_0 (Ohm component) represents an offset mho near side setting value;

X_0 (reactance component) represents an offset mho near side setting value;

R_F (Ohm component) represents an offset mho far side setting value; and

X_F (reactance component) represents an offset mho far side setting value.

A third embodiment of the present invention will

be described with reference to the accompanying

drawings. Description of the same configuration as

the above-described embodiments is omitted while like

reference numerals are attached thereto.

5   A protection relay of this embodiment comprises a

polarized voltage value calculator 12 in which voltage

v_{sm}, current i_{sm} and voltage v_{jm}, current i_{jm} are

inputted in order to extract voltage v_{pim} normal to

voltage v_{sm} and an operation decision section 13 in

10   which the aforementioned voltages and currents are

inputted while voltage v_{pim} is inputted from the

polarized voltage value calculator 12 so as to

decide whether or not it is active according to

the expression (30).

15   $v_{pjm-p} \cdot ((Rs \cdot i_{sm} + Xs \cdot i_{jm}) - v_{sm}) -$

$v_{pjm} \cdot ((Rs \cdot i_{sm-p} + Xs \cdot i_{jm-p}) - v_{sm-p}) \geq K2$ $\cdots (30)$

In the meantime, R_S and X_S are setting value

s of an Ohm component and a reactance component

respectively, while X_S is corrected in the form of

20   $X_S \leftarrow X_S / (\sin(\omega 0 T) / (k + 2 \cdot \cos(\omega 0 T)))$.

In the expression (30), the quantities of

electricity in the item of $(R_S \cdot i_{sm} + X_S \cdot i_{jm})$ and item

of $(R_S \cdot i_{sm-p} + X_S \cdot i_{jm-p})$ are in such a relation that

they are advanced only in size of $(R_S^2 + X_S^2)^{1/2}$ and

25   phase of $\phi = \tan^{-1}(X_S/R_S)$ with respect to current i_{sm}.

Its example will be shown in FIG. 13.

If current $i = I \cdot \sin(\omega t)$ and voltage

$v = V \cdot \sin(\omega t + \theta)$ are inputted to the first filter 1 of the transfer function $f(Z) \cdot (1 - k \cdot Z^{-1} + Z^{-2})$ and the second filter 2 of the transfer function $f(Z) \cdot (1 - Z^{-2})$, the expression (31) is established, providing that

5      $f(Z) = (1 + Z^{-1} + Z^{-2} + \cdots + Z^{-n})$:

$V_{pj} \cdot \{R_s \cdot I_s \cdot \cos(\theta) + X_s / (\sin(\omega_0 T) /$

$(k + 2\cos(\omega_0 T))) \cdot I_j \cdot \sin(\theta)) - V_s\} \cdot \sin(p\omega T) \geq K2$

where: $I_s = I(k + 2\cos(\omega T))(\sin((n+1)\omega T/2)/\sin(\omega T/2))$

$V_s = V(k + 2\cos(\omega T))(\sin((n+1)\omega T/2)/\sin(\omega T/2))$

10      $I_j = 2I\cos(\omega T/2)\sin((n+1)\omega T/2)$ $\cdots$ (31)

Then, if the expression (31) is expressed with Z_s (size: $(R_s^2 + X_s^2)^{1/2}$ and phase $\phi = \tan^{-1}(X_s/R_s)$, expression (32) is established. Therefore, the expression (32) indicates operation principle

15   expression of mho characteristic shown in FIG. 14 if its frequency is basic frequency.

$Vpj \cdot \{(Z_s \cdot I_s \cdot \cos(\theta)\cos(\phi) + Z_s \cdot I_j \cdot \sin(\theta)\sin(\phi)/$

$(\sin(\omega_0 T)/(k + 2\cos(\omega_0 T)) - V_s) \cdot \sin(p\omega T)$

$= Vpj \cdot \{Z_s \cdot I \cdot (\cos(\theta)\cos(\phi)(k + 2\cos(\omega T))/$

20      $\sin(\omega T) + \sin(\theta)\sin(\phi)$

$(k + 2\cos(\omega_0 T))/\sin((\omega_0 T)) - V_s\} \cdot \sin(p\omega T)$

$\because \omega = \omega_0$

$= Vpj \cdot \{Z_s \cdot I \cdot \cos(\theta - \phi) - V_s\} \cdot \sin(p\omega T) \geq K2$ $\cdots$ (32)

The above-described structure indicates a case

25   where voltage v_{pjm} normal to voltage v_{sm} in the fundamental wave is extracted by the polarized voltage value calculator 12. The present invention is not

restricted to this example. For example, it is
permissible to provide with a polarized voltage
value calculator 14 which regards a voltage before
predetermined cycles (data before N samplings) of the
voltage v_{jm} normal to voltage V_{sm} as polarized voltage
as shown in FIG. 15. In this case, the voltage v_{pjm}
and voltage v_{sm} are indicated in the expression (33).

$$v_{pjm} = 2V \cdot \sin((n+1)\omega T/2) \cdot \cos(\omega T/2)$$
$$\cdot \cos(\omega tm + \theta = N\omega T - (n+2)\omega T/2)$$
$$v_{sm} = V \cdot (k + 2\cos(\omega T)) \cdot \sin((n+1)\omega T/2)/$$
$$\sin(\omega T/2) \cdot \sin(\omega tm + \theta - (n+2)\omega T/2) \qquad \cdots (33)$$
$$(N\omega_0 T = 2\pi \cdot M, \text{ M is an integer})$$

It is permissible to provide with a polarized
voltage value calculator 15 for extracting voltage v_{pim}
normal to voltage v_{sm} as shown in FIG. 16 and if this
is for detecting a short-circuit, in case of, for
example, AB phase, extract positive sequence voltage
relative to the AB phase. A, B, and C indicate each
phase of three-phase AC quantity of electricity.

For example, positive sequence voltage relative
to the AB phase can be extracted according to
$v_{psm}(AB) = -3^{1/2} (v_{jm}(C) - v_{jm}(0)) + v_{sm}(AB)$. Here,
$v_{sm}(0)$ indicates zero phase quantity of electricity.

Further, if this is for ground fault, the positive
sequence voltage relative to A phase can be calculated
according to $v_{psm}(A) = 3^{1/2} \cdot (v_{sm}(A) - v_{sm}(0) + v_{jm}(BC)$.

In addition to the method for extracting voltage

vector from two electricity quantities normal to each other, it is permissible to apply a method in which sampling time series is shifted by 90° or equivalent.

Consequently, amplification of error due to

5   approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage

10 and fault current of power system thereby improving reliability.

A fourth embodiment of the present invention will be described with reference to FIG. 17. Description of the same configuration as the above-described

15 embodiments is omitted while like reference numerals are attached thereto.

FIG. 17 is a block diagram of a protection relay applied to description of this embodiment. According to the fourth embodiment, outputs from the first filter

20 1 and the second filter 2 are inputted to a charging current compensation calculator 16 and its output is inputted to an operation decision section 18 which follows operation decision principle of ratio differential relay type so as to decide whether or not

25 it is active.

The charging current compensation calculator 16 corrects a setting value C_S in the form of

$C_S \leftarrow C_S \cdot (k+2\cos(\omega_0 T)/\sin(\omega_0 T)$ and calculates $i_{sm}-C_S \cdot v_{jm}$ using output current i_{sm} from the first filter 1 and output voltage v_{jm} from the second filter 2. In the meantime, $C_S \cdot v_{jm}$ indicates current

5   compensation generated by charge capacity C_S.

Then, opposing quantity of electricity $(i_{sm}-C_S \cdot v_{jm})B$ of an opposite terminal is received by transmission and reception section 17 and quantity of electricity of itself terminal is transmitted to the

10   electric power station. Here, B indicates quantity of electricity at an opposite terminal.

After that, the operation decision section 18 decides the operation based on vectorial sum of current which compensates for charge current at itself terminal

15   obtained by the charging current compensation calculator 16 and current which compensates for charge current at a terminal of the opposite terminal, namely, scalar sum of amplitude value of differential current and currents which compensate for charge current

20   at each terminal, according to expression (34):

$$\| (i_{sm}-Cs \cdot v_{jm}) + (i_{sm}-Cs \cdot v_{jm})B \| \geq$$
$$ka \cdot \{ \| (i_{sm}-Cs \cdot v_{jm}) \| + \| (i_{sm}-Cs \cdot v_{jm})B \| \}+kb$$
$$\cdots (34)$$

where, $\|am\|$ represents quantity parallel to amplitude of

25   AC quantity of electricity at time t_m;

ka represents a proportion restricting coefficient; and

kb represents minimum sensitivity current.

Physical meaning of the charging current

compensation indicated in the expression (34) will be

described with reference to a power transmission line

in FIG. 18. A well known telegraph equation is

expressed at transmission/reception terminal as shown

in expression (35). Then, if Taylor expansion

approximation is executed on differential current i_{DD}

(t) with the condition of ($\tau \fallingdotseq 0$), the expression (36)

is obtained:

Waveform of forward movement:

$$i_{DF}(t)=i_S(t-\tau)+e_S(t-\tau)/z+i_R(t+\tau)-e_R(t+\tau)/z$$

Waveform of backward movement:

$$i_{DB}(t)=i_S(t-\tau)-e_S(t-\tau)/z+i_R(t+\tau)+e_R(t+\tau)/z$$

Differential current: $i_{DD}(t)=(i_{DF}(t)+i_{DB}(t))/2\cdots(35)$

where, suffix S represents a transmitting terminal;

      R represents a receiving terminal;

      Z represents a surge impedance =; and

      τ represents propagation time = $1/\nu$ (LC).

$$i_{DD}(t) = i_S(t) - (\tau/z)\frac{de_S(t)}{dt} + (\tau^2/z)\frac{d^2e_S(t)}{dt^2} - (\tau^3/3!z)\frac{d^3e_S(t)}{dt^3}\cdots$$
$$+ i_R(t) - (\tau/z)\frac{de_R(t)}{dt} + (\tau^2/z)\frac{d^2e_R(t)}{dt^2} - (\tau^3/3!z)\frac{d^3e_R(t)}{dt^3}$$
$$\cdots(36)$$

$\because \tau/Z=\Sigma C/2$ (1/2 charge capacity in entire SR

interval)

Even if differential current is extracted with

only current vectorial sum current ($i_S(t) + i_R(t)$) at

the transmission/reception terminal, the aforementioned

charge current component becomes error current, thereby
inducing a drop of sensitivity of the differential
relay. Thus, only a fault current component can be
extracted by compensating for this.

$$i_{DD}(t) = i_S(t) - (\tau / z)\frac{de_S(t)}{dt} + i_R(t) - (\tau / z)\frac{de_R(t)}{dt} \quad \cdots (37)$$

In the above description, the transfer
function f(Z) in the first filter 1 and the
second filter 2 has been described in the form of
$f(Z) = (1+Z^{-1}+Z^{-2}+ \cdots +Z^{-n})$. It is evident that the
same effect can be obtained even if the transfer
function is $f(Z) = (1+Z^{-2}+Z^{-4}+ \cdots +Z^{-2n})$.

In this case, in the expression (10), $\omega T/2$ only
should be replaced for ωT and in that case, the
expression (38) is established. Likewise, the
expressions (8) and (12) only should be replaced.
For convenience of following description, it is
described that $f1 = f(Z) = (1+Z^{-1}+Z^{-2}+ \cdots +Z^{-n})$, and
$f2 = f(Z) = (1+Z^{-2}+Z^{-4}+ \cdots +Z^{-2n})$.

$$i'_{sm} = I \cdot (\sin(\omega t_m) + \sin(\omega t_m - 2\omega T) + \cdots + \sin(\omega t_m - 2n\omega T))$$
$$= I \cdot (\sin((n+1)\omega T)/\sin(\omega T)) \cdot \sin(\omega t_m - n\omega T) \quad \cdots (38)$$

If f1 is replaced to f2, the quantity of data in
the latter can be reduced assuming that the window
length of data for use is the same and approximation
error of integration is of the same value. For
example, if n = 2 is adapted in case of f1, n = 1 may
be adapted in case of f2.

Because gain in the first filter 1 and the second filter 2 using f1 is larger than gain in the first filter 1 and the second filter 2 using f2, noise error can be compressed by that amount.

5   For example, when f1 is used, gain G1 of n = 2 is expressed in the expression (39) and if f2 is used, gain G2 of n = 2 is expressed in the expression (40).

$$G1 = | \sin(3\omega T/2)/\sin(\omega T/2) | = | 2\cos(\omega T) + 1 | \qquad \cdots (39)$$

$$G2 = | \sin(2\omega T)/\sin(\omega T) | = | 2\cos(\omega T) | \qquad \cdots (40)$$

10   Such transfer function f(Z) is constructed with FIR fileter. The present invention is not restricted to this example, but the same integration error characteristic can be achieved even when it is constructed with recursive digital filter.

15   Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence

20   even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

According to the present invention, as described above, even when a harmonic component is overlaid on

25   a fault current and a fault voltage generated upon a fault of a power system, a predetermined time differential equation can be solved approximately by

passing through predetermined digital filters normal to each other in a wide frequency band, thereby achieving a high accuracy protection relay.

Additional advantages and modifications will
5   readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the
10   spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.